AN EVALUATION OF PROCEDURES FOR IMPROVING WATER QUALITY IN A SKI AREA

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AN EVALUATION OF PROCEDURES FOR IMPROVING WATER QUALITY IN A SKI AREA

by

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Introduction

Man's use and development of wildlands in the Rocky Mountains is expected to increase significantly in the near future. A significant recreational use of forested areas in the region is that of ski area development and use. The high elevations, high precipitation, steep slopes, and high people density associated with these areas predict significant interactions between this land use activity and water quality. The effect of this increased human impact is difficult to assess because of the complexity of natural ecosystems and the lack of information about the delicate adjustments that maintain a balance in these systems. As a result land managers have difficulty in predicting the full range of consequences that a particular development will have. The issue is further complicated because of the pressure on land managers to emphasize maximizing the output of some product or service with less importance being placed on the secondary effects. It is imperative that procedures and tools be developed which can aid land managers in predicting the full consequence of land use as well as minimizing adverse effects.

Problem

Our past and current studies on ski area development have been involved with quantifying the effect of ski area development on water quality and demonstrating the value of an ecosystem approach in the identification of causal factors (Gosz 1975a, 1977). These studies demonstrated that the most significant effect on water quality resulted from the application of road salt for snow removal. The effects of the salt application

were not only the increased levels of NaCl in stream water but also increased Ca, Mg, K, NO_3-N, NH_4-N, organic N, and sediment levels as a result of changes in soil structure and chemistry. Increased concentrations of heavy metals also occurred (Pb, Zn, Cu), primarily the result of increased sediment levels (Moore et al. 1978). These results suggest several ameliorating procedures for water quality subject to ski area development and use; reducing stream discharge, increasing revegetation rates, and decreasing road salt application.

Purpose

The purpose of this study was to demonstrate how improvements in water quality could be made through modifications of land use activity.

Objectives

The specific objectives of this study were to:

1. To quantify the improvement in water quality resulting from the closure of about 60% of the road in the drainage basin and increasing the revegetation acreage.
2. To quantify the effect on water quality of diverting the stream around heavily used portions of the ski area.
3. To use the results developed in previous objectives to formulate guidelines with which existing or new ski areas can minimize the damage to aquatic ecosystems.

Study Area

The Santa Fe Ski Basin makes an ideal study area for our research. It is located at the headwaters of the Rio en Medio which is a perennial stream. The ski basin watershed can be divided into three drainage areas based upon types of useage and topographic boundaries (fig. 1). The upper area (area 1; 163 ha) is only affected by skiing activity (ski runs, poma lifts) and the stream is gauged which gives us detailed water discharge rates and yield data. Studies of water chemistry over the past ten years show consistant levels or patterns and allow us to use this area as a control.

The middle portion of the ski basin (area 2; 92 ha) is the drainage area for most of the ski runs plus chair lifts, a parking lot, drainfields from the waste disposal systems of two lodges, and 0.8 km of road subject to road salting practices. A stream diversion, consisting of a gate dam and underground pipe, diverts the stream from area 1 out of the study area (fig. 1). Therefore, water quality data collected from area 2 reflect impacts on that area. Our past studies demonstrate a significant change in water quality in area 2 primarily as a result of road salt application.

The lower portion of the ski basin (area 3; 4.9 ha) does not have skiing activity; however, it is affected by a parking lot and 0.5 m of road which is subject to road salting practices during the winter months.

Several significant modifications of land-use activity were planned which we were to study in terms of their effect on water quality. In area 2, virtually the entire 0.8 km of road would be closed to the public which means that no road salt would be applied. During the winter months the road bed would be used as a ski run. The parking lot at the upper lodge would have topsoil applied and the area would be revegetated. Since our

hypothesis is that road salt is the main causal agent in the change in water quality, these activities would allow us to test the hypothesis. The reduced exposure of mineral soil was expected to reduce the particulate level in the stream as well as the heavy metal levels. The closure of one of the parking lots would require the construction of new lots in area 3. This was expected to decrease the water quality originating from area 3; however, we hypothesized that the overall quality of water in the Rio en Medio would be improved because of the decreased length of road in the basin receiving road salt. The actual construction and revegetation activities were to be performed by ski area personnel under the supervision of the U.S. Forest Service. Our role was that of quantifying the effects of these activities through the use of water quality data.

Unfortunately, although the above activities were planned for 1976-77, they were not initiated until the summer of 1979. New parking lots were constructed (see fig. 1), however, the old upper parking lot at the upper lodge was not revegetated. It will be revegetated during the summer of 1980. The road in area 2 was closed during the 1980 ski season and road salt application only occurred in area 3 of the ski basin. Our results, therefore, represent the initial stages in any improvement in water quality through these procedures.

Methods

Precipitation -- Precipitation was measured by a combination of standard and recording rain gauges on seven stations located at 300 m intervals over the elevational gradient. Regressions of precipitation on elevation were calculated for annual precipitation and applied to individual areas of the ski basin to estimate the weighted areal precipitation.

Streamflow -- Streamflow was measured continuously at the base of area 1 by a gauging station. During the winter months the weir is heated to prevent ice from forming on the V-notch. Areas 2 and 3 are not gauged; therefore, discharge volumes were calculated using the weighted areal precipitation and evaporation data for the elevational range of the ski basin (see Gosz 1975b). They were also calculated using the Cl concentrations of the area and area 1 discharge. Samples of stream water for chemical analysis were collected weekly at the base of each area of the ski basin except during periods of high discharge or construction activity when more frequent sampling occurred.

Chemical Analyses -- Analyses of stream water and precipitation were made for Ca, Mg, Na, K, NH_4-N, NO_3-N, organic N, Cl, and sediment. Cation analyses were performed by atomic absorption spectrophotometry while nitrogen and chloride analyses were performed by Technicon Autoanalyzer procedures. Sediment analyses were performed gravimetrically after filtration.

Results

Stream Diversion

The relationship between stream discharge and sediment concentrations is well recognized (Bormann et al. 1974). The reduction in stream discharge and velocity in areas 2 and 3 as a result of the stream diversion can be expected to reduce sediment levels. Since a large portion of the heavy metal concentration in stream water is associated with the sediment (Moore et al. 1978), the water diversion will also reduce heavy metal transport.

It is more difficult to predict how levels of soluble ions will respond to changes in stream discharge. Therefore, stream discharge in area

2 was manipulated by opening the diversion gate and allowing the complete stream from area 1 to flow through area 2. This procedure was performed during July 13-15, 1977. The results (figures 2-5) show marked changes in every ion.

The discharge from area 1 on July 13 (fig. 2) shows a typical pattern for July of lower values during late afternoon-early evening due to evapotranspiration. During the 24 hour period when the diversion gate was open, a 1.3 cm rain occurred which increased the discharge rate significantly. After the diversion gate was closed (July 15), another increase in stream discharge occurred. These fortuitous events allow additional insite into the influence of stream discharge on stream chemistry.

The effect of increasing stream discharge on Na and Cl is shown in figure 3. The pattern for Na shows little change throughout July 13 but a significant drop starting about 45 minutes after the diversion gate at the top of area 2 was opened. This delay corresponded to the length of time it took the additional water to move down the stream channel to the base of area 2. It took a total of about 3 hours for the Na concentrations to stabilize.

After the diversion gate was again closed, Na concentrations increased over a 3 hour period to a stable value which was somewhat lower than the original concentrations of July 13. This may have been the result of the elevated base-flow in the stream (see fig. 2). The storm which occurred at 2200 hours on July 14 did not influence Na levels, however, the smaller increase in stream discharge on the 15th caused a marked increase.

The Cl pattern was similar to that for Na with the exception that the elevated stream discharges of both July 14 and 15 caused increases in Cl

concentrations. Although the storm on July 14 caused a higher stream discharge, the increase in Cl was not as great as on July 15 (see fig. 3). One explanation is that the increase in Cl levels lagged behind the increase in stream water. Although the collection at 2200 hours on July 14 was at peak discharge, maximum Cl concentrations may have occurred sometime after that; the next collection was not made until 0600 hours July 15. On July 15, a collection made 2 hours after peak discharge showed a higher concentration than the collection at peak discharge. This would be possible if additional time was required for soil moisture from the salt-enriched regions of area 2 to reach the stream. This may also explain why Na did not demonstrate a response on July 14 but did on July 15. The difference between Na and Cl would be due to the greater mobility of the Cl anion in soil (Hem 1970).

Calcium, Mg, and K showed patterns somewhat similar to Na and Cl with the exception that after opening the diversion gate the initial surge of additional water carried increased Ca, Mg and K levels (fig. 4). The increase occurred 45 to 60 minutes after the gate was opened; the time required for the additional water to move down to the collection point. This was the result of increased sediment and organic material picked up from the sides of the stream channel and washed downstream. It was followed by the clean water of area 1 causing the expected dilution.

An important consideration is whether the dilution is totally the result of the chemistry of the additional water from area 1. This can be answered by comparing the discharge and chemistry of area 2 after the diversion gate was opened to that before gate opening plus the additional water from area 1. Area 1 discharge was measured, however, area 2 discharge must be calculated. This can be done using Cl which is very mobile

and is essentially not affected by geological activity (Hem 1970). Area 2 discharge can be calculated using the formula:

$$\left[\begin{smallmatrix}\text{area 2}\\\text{discharge}\end{smallmatrix} + \begin{smallmatrix}\text{area 1}\\\text{discharge}\end{smallmatrix}\right] \left[\begin{smallmatrix}\text{area 2}\\\text{Cl conc.}\end{smallmatrix}\right] = \left[\begin{smallmatrix}\text{area 2}\\\text{discharge}\end{smallmatrix}\right] \left[\begin{smallmatrix}\text{area 2}\\\text{Cl conc.}\end{smallmatrix}\right] + \left[\begin{smallmatrix}\text{area 1}\\\text{discharge}\end{smallmatrix}\right] \left[\begin{smallmatrix}\text{area 1}\\\text{Cl conc.}\end{smallmatrix}\right]$$

Selecting a specific time during the period the diversion gate is open (e.g. 1600 hours, July 14), the discharge of area 1 is known, the Cl concentration in area 2 is known, and the Cl concentration in area 1 is known. The normal concentration of Cl in area 2 is assumed to be equal to the measured Cl at 1600 hours on July 13 when the diversion gate was closed. Thus; solving for area 2 discharge (x):

$$[x + .373]\ [2.69] = [x]\ [7.19] + [.35]\ [.14]$$

$$x = .21 \text{ cfs}$$

Knowing the discharge rates for both area 1 and 2 allow a comparison of the actual concentration of an element in the water of area 2 when the diversion gate is open with the expected concentration resulting from the mixture of water from area 1 and 2.

Table 1 gives the measured concentrations of nutrients in area 2 stream water at 1600 hours July 14, the expected concentrations, and the ratio of the two. Calcium, Mg, Na, K, and NO_3-N values are similar enough to suggest that the concentration changes shown are the simple result of mixing two waters of different chemistries. Two ions, NH_4 and SO_4, are different enough to suggest that instream factors are causing additional effects. The actual NH_4 concentration was 25% lower than expected suggesting biological uptake (see fig. 5). The nitrogen may have been immobilized in the tissue of stream organisms (Fogg et al. 1973, Stewart 1974) or volatilized (Kaushik et al. 1975). Sulfate behaved very differently than other ions (fig. 5). Stream concentrations of SO_4 were greater in area 1 than in area

2 causing an increase in area 2 after the diversion gate was opened, however, the actual increase was 40% greater than expected due to the simple mixing of the two waters. The most logical explanation is that the higher discharge following the opening of the diversion gate caused increased flooding and flushing of stream-side marshy areas near the base of area 2. These areas are known to have iron oxidizing bacteria which cause the accumulation of precipitated iron oxides. These same areas would also have sulfur oxidizing bacteria (Hem 1970) so a flushing by increased discharge could remove a portion of accumulated sulfates. It is also possible that the addition of more oxygen-rich water to these areas could increase the activity of sulfur oxidizing bacteria. The somewhat slower change in SO_4 concentrations following the opening of the diversion gate supports the above discussion.

Management Activity

Construction of new parking lots did not start until the summer months of 1979 and the revegetation of an old parking lot has not yet been started. The new parking lots did allow the closure of the road in area 2 and the elimination of road salting in that area during the 1979-80 winter. Stream samples were collected during the period June-November, 1979, and compared with data from the same period in 1976. Precipitation volumes were very similar for these two periods ($\approx$30 cm).

Table 2 contrasts the stream chemistry of areas 2 and 3 in both 1976 and 1979. In 1976, as in most years at the ski basin, the nutrient concentrations in the stream in area 3 exceeded concentrations in the stream of area 2. This was due to the increased inputs caused by road salting in area 3 (Gosz 1975a, 1977). The higher average sediment concentration in area 2 during 1976 was due to a single collection which had a concentration of 196.2 mg/l. The corresponding concentration in area 3 was 80.2

mg/l; the difference is the result of construction activities in area 2. In 1979, a similar pattern occurred with values in area 3 generally higher than those in area 2. The major differences between the years 1976 and 1979 were lower concentrations during 1979 and higher levels of significance for the difference between area 2 and 3 in 1979. The increased level of significance in 1979 was primarily the result of reduced variation in nutrient concentrations allowing a more sensitive statistical test.

The differences between 1976 and 1979 were further tested by comparison of collections from each area (table 3). A comparison of area 1 during 1976 and 1979 generally shows nonsignificant differences, the exceptions being Ca and NH_4. This area is above the identified management activities and can be considered a control. Although the precipitation for the period June through November was similar during 1976 and 1979, stream discharge was somewhat higher in June of 1979 due to a larger snowpack and later snowmelt. The latter portion of the snowmelt period normally shows low concentrations of Ca (Gosz 1975b).

Comparisons of areas 2 and 3 show highly significant decreases of most nutrients during the 1979 period. Although suspended sediment levels decreased in both areas in 1979, the variability was too large to demonstrate a significant decrease. Ammonium levels did not change significantly between areas or between years.

Additional information comes from calculating ratios of nutrients and sediment between areas and years (Table 4). These suggest; 1) there was a larger decrease of nutrient concentrations from 1976 to 1979 for areas 2 and 3 than for the control (area 1), 2) the decrease in nutrient concentrations for area 2 was similar to the decrease in area 3, 3) the ratio between area 2 and area 3 was similar for 1976 and 1979 and 4) concentrations in both areas decreased proportionately in 1979.

It is tempting to say that the general improvement in water quality in areas 2 and 3 were the result of the new management activities. This is not necessarily true, however. We would expect that water quality would improve because of the elimination of road salting in area 2 but that change had not occurred by the time this study was conducted. The new parking lots have allowed the closure of the road in area 2 during the current winter (1979-80) and we expect a major improvement in area 2 starting in the spring of 1980. The most probable cause of the better water quality in 1979 was the reduced construction activity (e.g. ski runs) and the increased vegetation cover on ski runs constructed earlier. An important fact is that water quality remained in an improved condition in area 3 in spite of the intensive construction activity involved with making new parking lots. This demonstrates that these activities can be performed without significantly deteriorating water quality. The new parking lots will allow an additional improvement in the water quality of areas 2 and 3 because of the decreased road salting in area 2. The additional revegetation of an old parking lot in area 2 will further minimize the occurrence of adverse water quality. We expect to see these improvements start with the spring snow melt period of 1980 and continue for several years as revegetation becomes established and residual salt (from previous years) is removed from the system. The reduction in Na levels in the roadside area should be accompanied by increased improvement in soil structure (Gosz 1975a) which contributes further to improved water quality.

Management Guidelines

Although the management practices designed to improve water quality have not been established for a long enough period to completely determine their effectiveness, the results thus far are encouraging. Past studies have identified road salting as the major factor in altered water quality in the Santa Fe Ski Area. The closure of a significant portion of the road in the area as well as a parking lot adjacent to the stream is expected to markedly improve water quality. The degree of that improvement will become apparent starting in the spring of 1980 and continuing for several years. In order to close the road and upper parking lot, two new parking lots were constructed without impairing water quality in the Rio en Medio. This demonstrates that land disturbance activities can be performed successfully if careful consideration is given to topography, drainage patterns, etc. The new parking facilities also have improved the parking access and capacity of the ski area.

The stream diversion also has been an important management technique especially during the development phase involving ski run construction and revegetation. The influence of stream discharge on sediment levels is well established and becomes especially important in areas of soil disturbance. Our studies also indicate that most of the soluble ions behave in predictable ways in relation to changes in stream discharge. That predictability allows its affect to be estimated and included in a management plan.

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Table 1. Actual concentrations (mg/l) in the stream of area 2 after opening the diversion gate and the calculated concentrations based on the mixing of the area 1 and area 2 stream waters

ION	AREA 2 ACTUAL CONC.	AREA 2 CALCULATED CONC.	ACTUAL/CALC.
Ca	3.99	4.00	1.00
Mg	0.85	0.91	0.93
Na	2.69	2.72	0.99
K	0.60	0.56	1.07
NH_4-N	0.024	0.032	0.75
NO_3-N	0.042	0.44	0.95
SO_4	2.5	1.78	1.40

Table 2. Average nutrient and sediment concentrations (mg/l) for areas 2 and 3 of the Santa Fe Ski Basin during June through November of 1976 and 1979. Significant differences between areas (using a paired t test) are indicated with * ($p < .05$) or *** ($p < .001$). Nonsignificant differences are indicated by n.s.

	1976			1979		
	Area 2	Area 3	t Test	Area 2	Area 3	t Test
Sediment	10.64	6.55	n.s.	1.67	1.85	n.s.
Ca	5.56	5.75	*	3.46	3.61	**
Mg	1.20	1.24	*	0.77	0.82	***
Na	4.15	4.62	*	2.82	3.14	***
K	0.79	0.82	n.s.	0.58	0.61	***
NO_3	0.14	0.13	*	0.04	0.04	n.s.
NH_4	0.02	0.03	*	0.02	0.02	n.s.
Cl	8.77	10.04	***	2.72	3.79	***

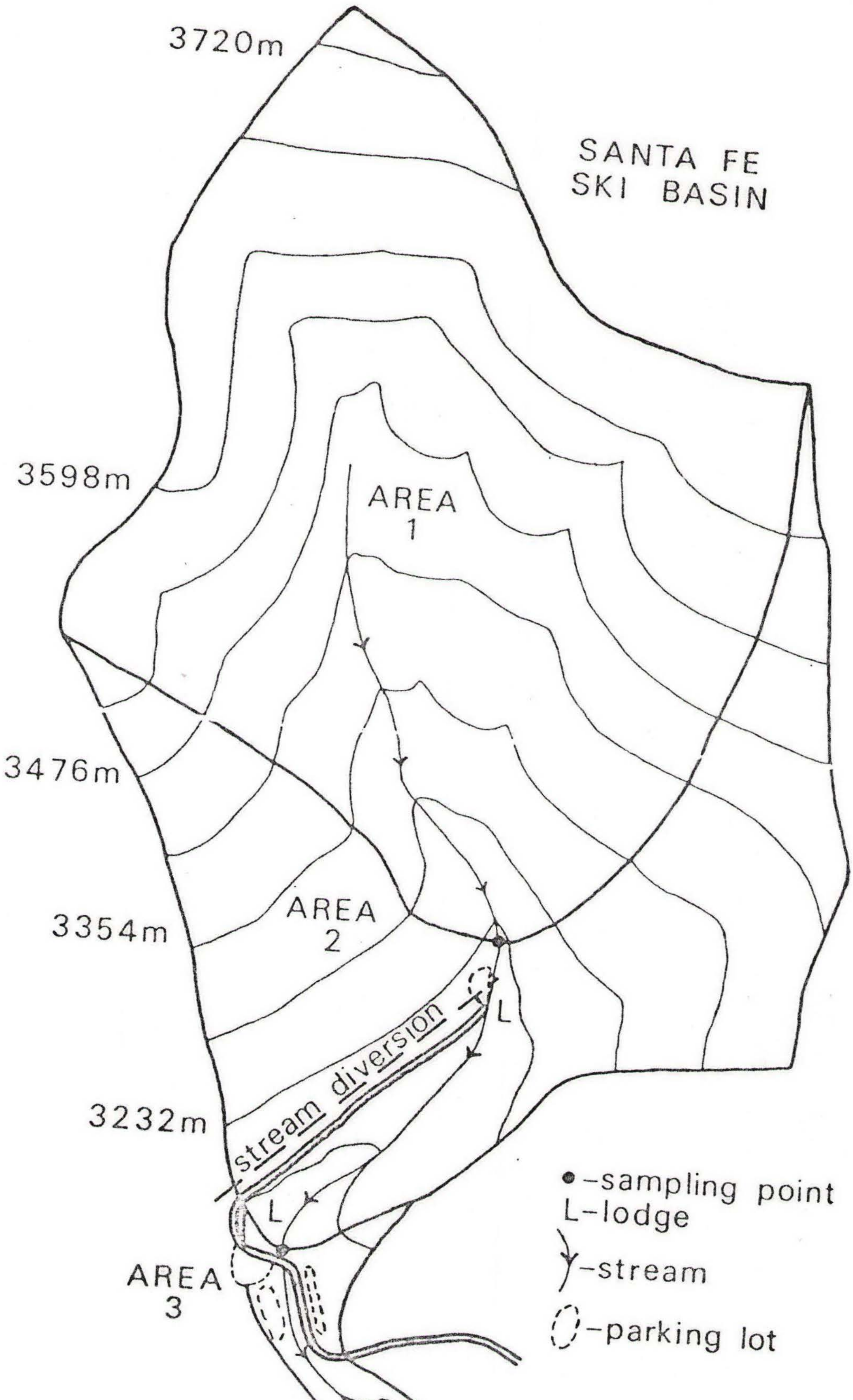
Table 3. Average nutrient and sediment concentrations (mg/l) for 3 areas of the Santa Fe Ski Basin during June through 1976 and 1979. Significant differences between years are indicated with * ($p < .05$), ** ($p < .01$) and *** ($p < .001$). Nonsignificant differences are indicated by n.s.

	Area 1 1976	Area 1 1979	t Test	Area 2 1976	Area 2 1979	t Test	Area 3 1976	Area 3 1979	t Test
Sediment	-	-		10.64	1.67	n.s.	6.55	1.85	n.s.
Ca	2.83	2.58	**	5.56	3.46	***	5.75	3.61	***
Mg	0.65	0.61	n.s.	1.20	0.77	***	1.23	0.82	***
Na	1.88	1.81	n.s.	4.15	2.82	***	4.62	3.14	***
K	0.50	0.47	n.s.	0.79	0.58	***	0.82	0.61	***
NO_3-N	0.07	0.03	n.s.	0.14	0.04	***	0.13	0.04	**
NH_4-N	0.02	0.03	*	0.02	0.02	n.s.	0.03	0.02	n.s.
Cl	0.28	0.38	n.s.	8.77	2.72	***	10.04	3.79	***

Table 4. Nutrient and sediment ratios for different years and areas on the Santa Fe Ski Basin

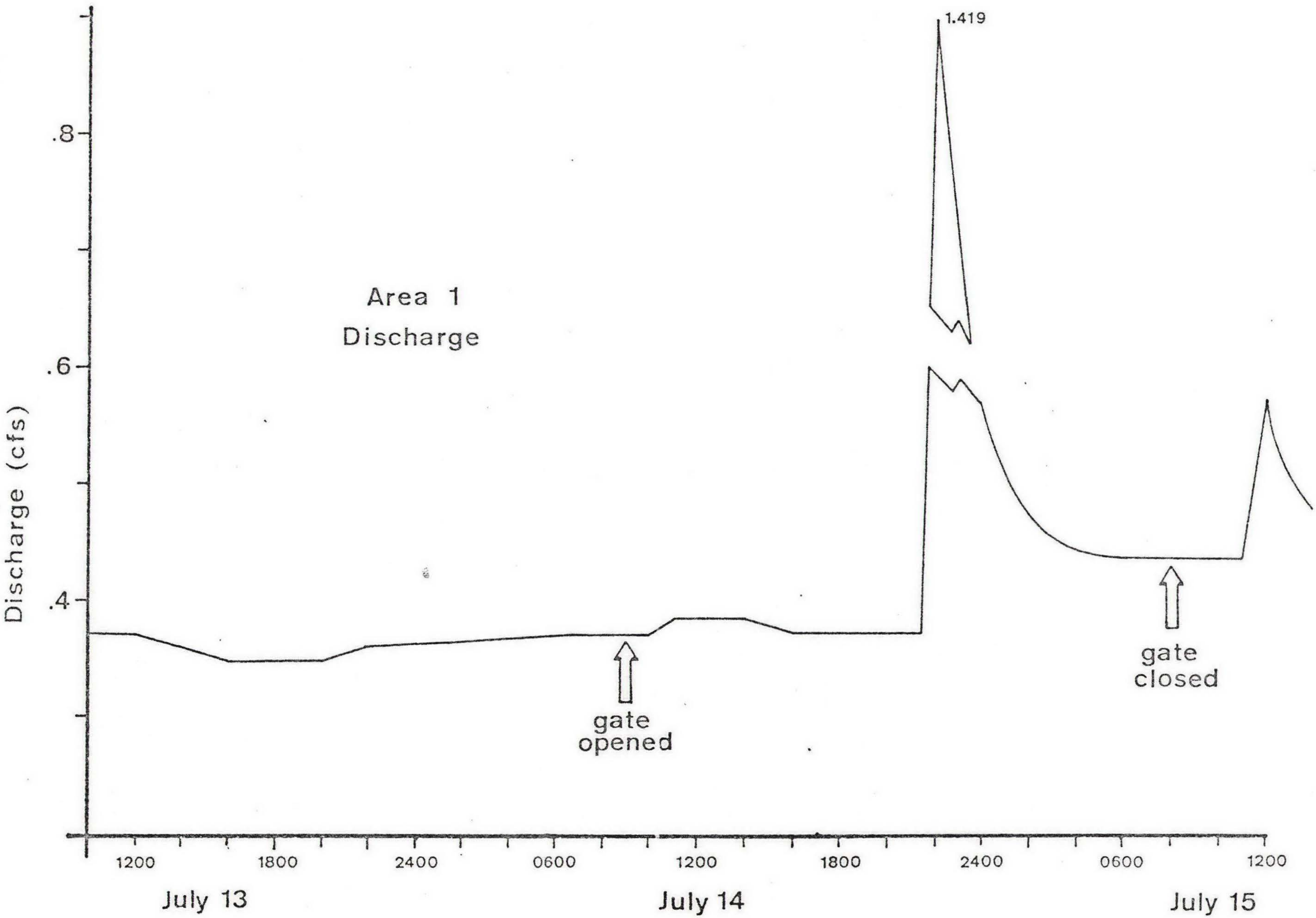
	Area 1 1976/1979	Area 2 1976/1979	Area 3 1976/1979	1976 Area 2/Area 3	1979 Area 2/Area 3
Sediment	-	6.39	3.54	1.62	0.90
Ca	1.10	1.61	1.59	0.97	0.96
Mg	1.07	1.56	1.50	0.98	0.94
Na	1.04	1.47	1.47	0.90	0.90
K	1.06	1.36	1.34	0.96	0.95
NO_3-N	2.33	3.50	3.25	1.08	1.00
NH_4-N	0.67	1.00	1.50	0.67	1.00
Cl	0.74	3.22	2.65	0.87	0.72

Figure 1. Santa Fe Ski Basin study area near Santa Fe, New Mexico. The stream in area 2 is diverted by an underground pipe out of the basin. The two lower parking lots were constructed in 1979.



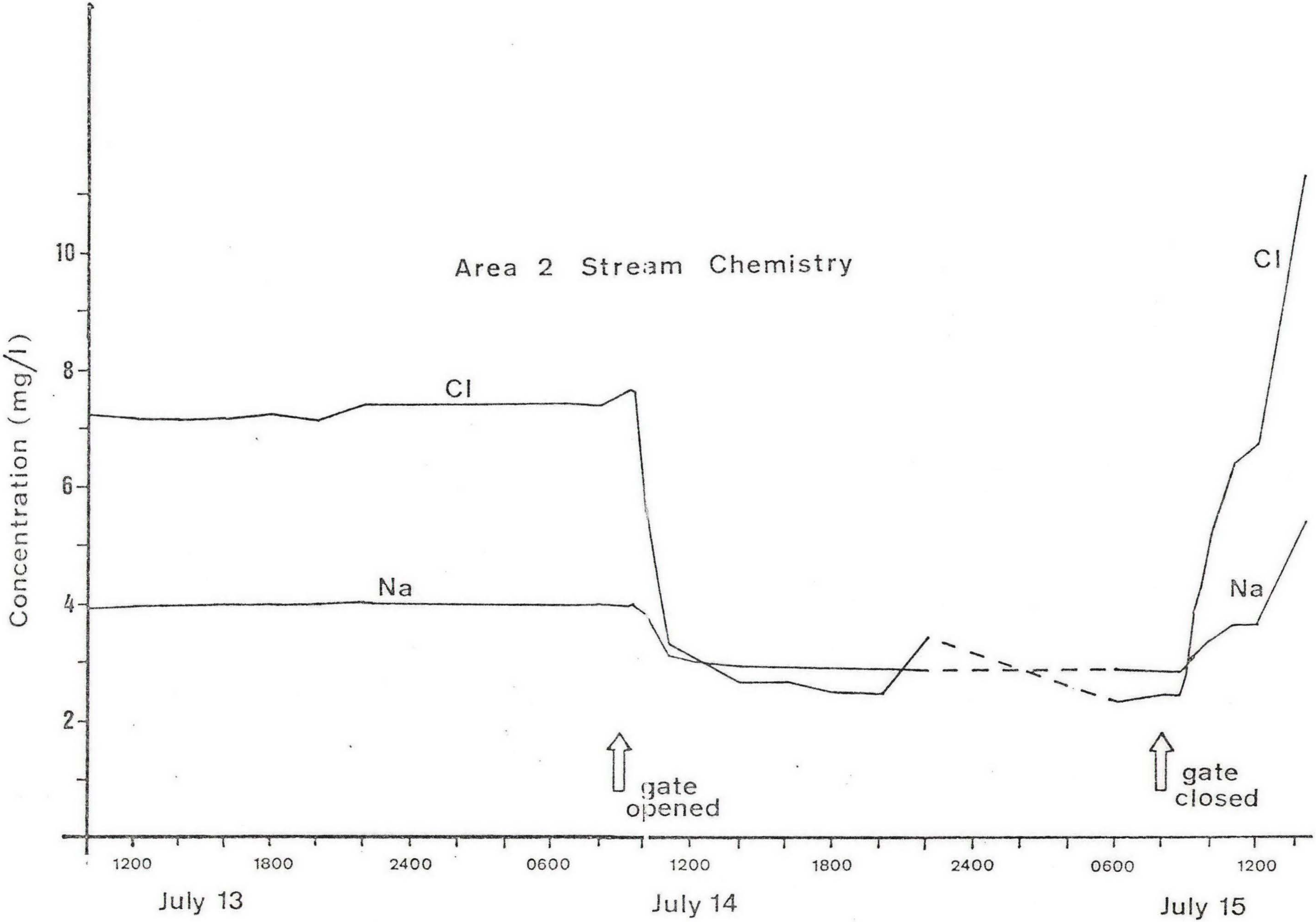
3720m
SANTA FE
SKI BASIN
3598m
AREA
1
3476m
AREA
2
3354m
L
stream diversion
3232m
L
AREA
3
-sampling point
L-lodge
-stream
-parking lot

Figure 2. Discharge rates for area 1 of the Santa Fe Ski Basin. At 0900 hours on July 14 the diversion gate was opened allowing this flow to enter area 2. The diversion gate was closed at 0800 hours on July 15.



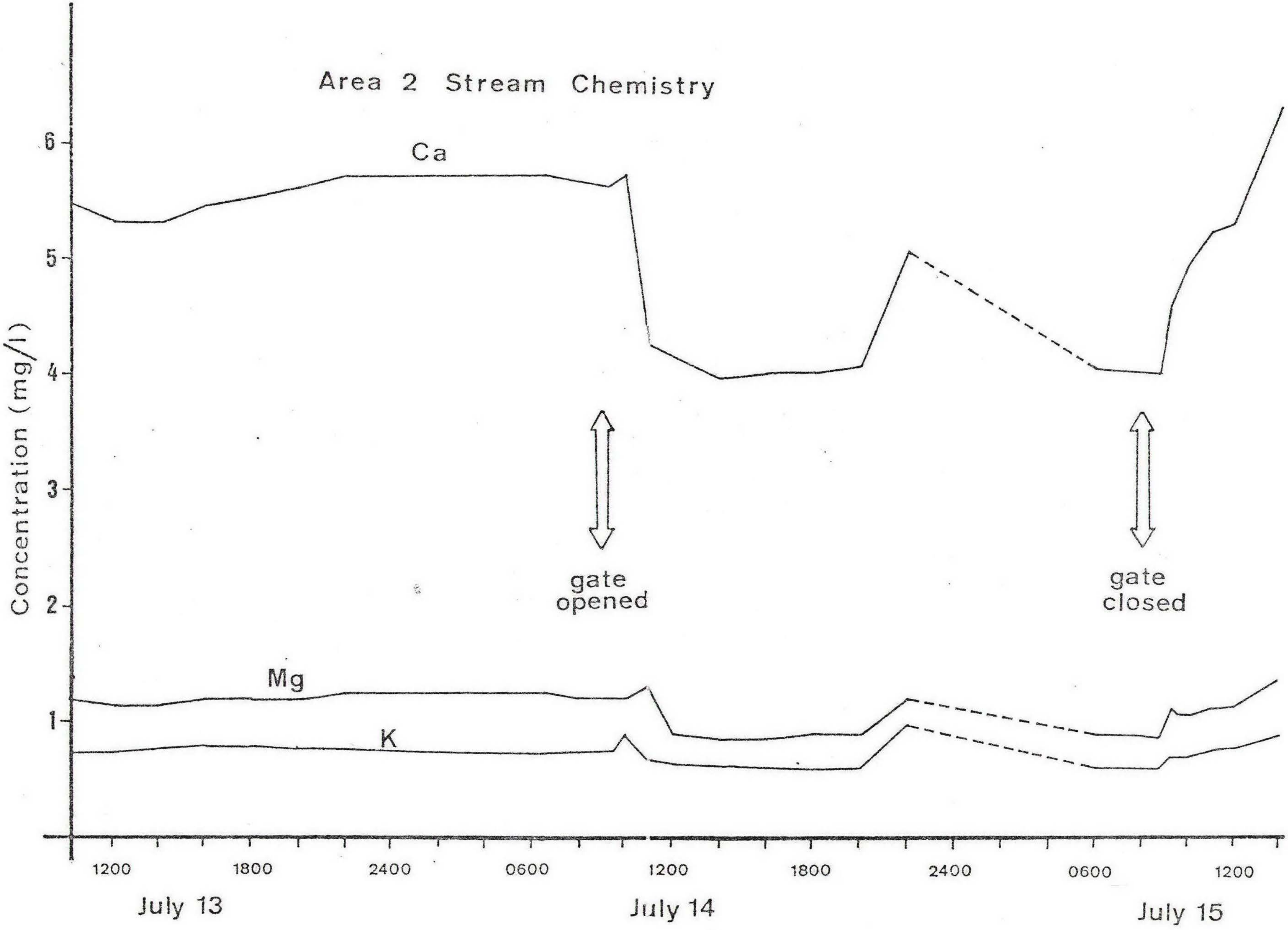
1.419
.8
.6
.4
Discharge (cfs)
Area 1
Discharge
gate
opened
gate
closed
1200
1800
2400
0600
1200
1800
2400
0600
1200
July 13
July 14
July 15

Figure 3. Sodium and C. concentrations in stream water collected at the base of area 2. The drop in concentrations was a result of the additional water from area 1 after the diversion gate was opened.



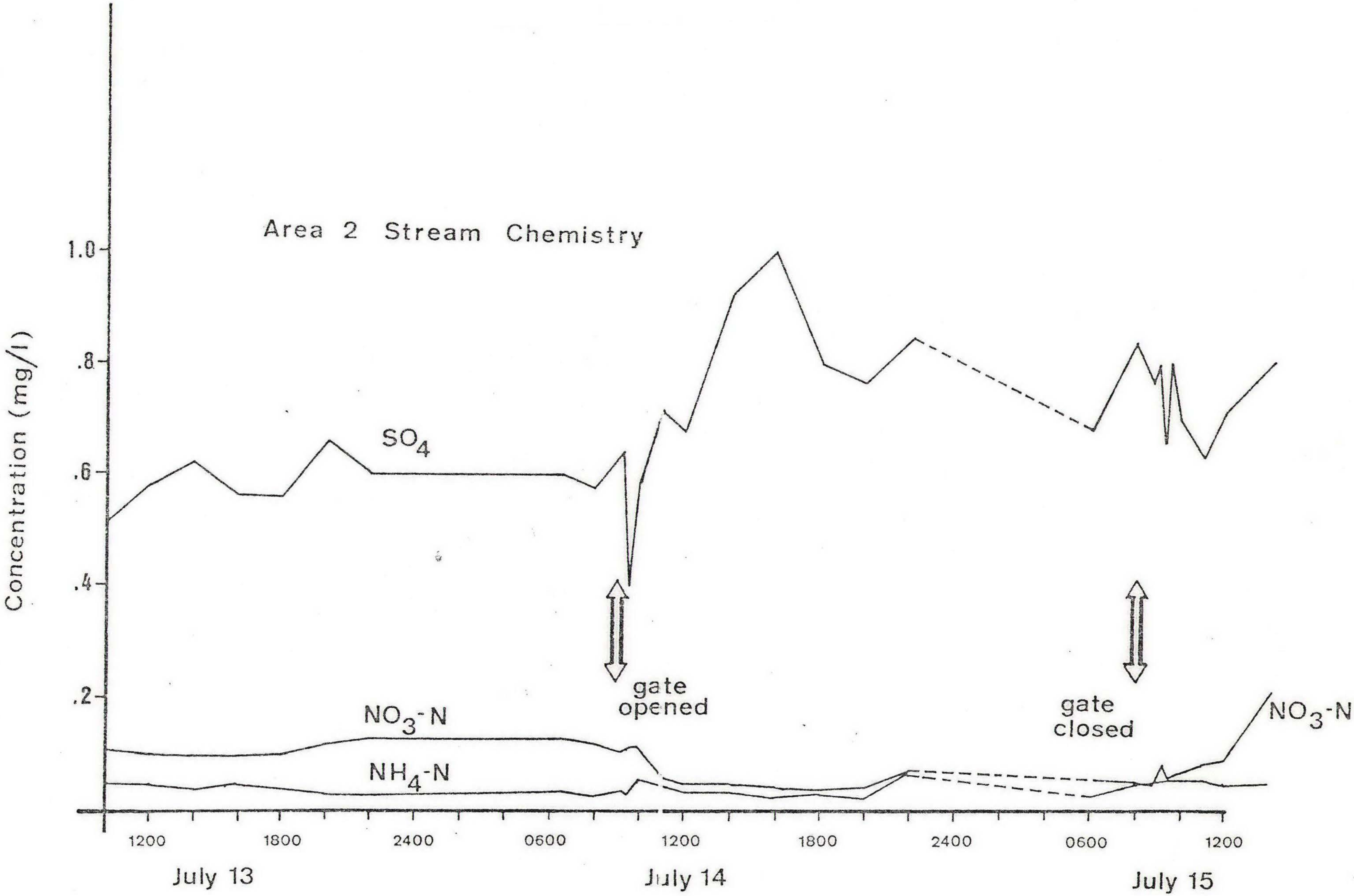
Area 2 Stream Chemistry
Concentration (mg/l)
10
8
6
4
2
Cl
Na
Cl
Na
gate opened
gate closed
1200
1800
2400
0600
1200
1800
2400
0600
1200
July 13
July 14
July 15

Figure 4. Calcium, Mg, and K concentrations in stream water collected at the base of area 2. Additional water from area 1 caused the pronounced drop in concentrations on July 14.



Area 2 Stream Chemistry
Ca
Mg
K
gate opened
gate closed
Concentration (mg/l)
1
2
3
4
5
6
1200
1800
2400
0600
1200
1800
2400
0600
1200
July 13
July 14
July 15

Figure 5. Sulfate, NO_3-N, and NH_4-N concentrations in stream water collected at the base of area 2. Additional water from area 1 caused the drops for NO_3-N and NH_4-N and increases for SO_4 on July 14.



Area 2 Stream Chemistry
Concentration (mg/l)
1.0
.8
.6
.4
.2
SO_4
NO_3-N
NH_4-N
gate opened
gate closed
NO_3-N
1200
1800
2400
0600
1200
1800
2400
0600
1200
July 13
July 14
July 15